Optimal conditions for light pulses coherence transformation in thin nonlinear media

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ABSTRACT

Via solution of appropriate variational problem it is shown that light beams with Gaussian spatial profile and sufficiently short duration provide maximal destruction of global coherence under nonlinear self-modulation.

Keywords: nonlinear phase self-modulation, controllable coherence degradation.

1 INTRODUCTION

Earlier it was demonstrated,[1] that self-modulation of light fields in a nonlinear medium can serve as a convenient tool for controllable coherence manipulation. Process of local interaction of coherent incident field $E_{in}(\mathbf{r},t) = \mathcal{E}(\mathbf{r})e(t)$ with "optically thin" nonlinear layer, being described by Raman-Nath approximation, causes different nonstationary phase shifts

$$E_{out}(\mathbf{r},t) = E_{in}(\mathbf{r},t) \exp\left\{ i\Phi(|E_{in}(\mathbf{r},t)|^2) \right\}, \tag{1}$$

where the phase is determined by media parameters and intensity of input light in every particular point $\mathbf{r}$ of a beam cross-section. The resulting degradation of spatial coherence can be treated as a decay of initially single-mode (but nonuniform) radiation into a number of mutually incoherent, orthogonal modes. Such a process imitates the action of moving phase diffuser and can in principle be used for speckle-noise reduction in experiments with short light pulses.

The main characteristic of output field in discussed process is an overall degree of coherence

$$\mu = \frac{1}{U^2} \int dt_1 \int dt_2 \big| K(t_1,t_2) \big|^2, \tag{2}$$

where

$$K(t_1,t_2) = \int d^2 r\, E_{out}(\mathbf{r},t_1) E^*_{out}(\mathbf{r},t_2) \tag{3}$$

is a spatially averaged temporal correlation function, and

$$U = \int d^2 r \int dt |E_{in}(\mathbf{r},t)|^2 = \int dt\, K(t,t)$$

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— pulse energy (nonlinear medium is supposed to be absorbtionless). The value (2) determines the contrast of all interference phenomena (including speckles) and it is closely connected with coherent-mode structure of optical fields. Modal treatment is an analogue of Karhunen-Loéve transformation, and the main parameter of such approach — effective number of modes — is $N_{eff} = 1/\mu$ (see Ref. 2, 3 for further details).

2 OPTIMISATION OVER SPATIAL BEAM DISTRIBUTION

The consideration in paper[1] was carried out for the model of cubic nonlinearity with exponential relaxation and speckled input field. Maximal coherence destruction there is achieved in the ultimate case of inertial interaction with infinite memory

$$\Phi(|E_{in}(\mathbf{r},t)|^2) = \eta \int_{-\infty}^{t} dt |E_{in}(\mathbf{r},t)|^2. \tag{4}$$

For this limit the value (2) does not depend on temporal shape of input pulse, and every initial field is equivalent to rectangular pulse of duration T:

$$E_{in}(\mathbf{r},t) = \begin{cases} \mathcal{E}(r)/\sqrt{T}, \ 0 < t \le T \\ 0, \ elsewhere \end{cases}$$

The interaction with infinite memory provides maximal total phase shift, so one can expect, that the case (4) will result in maximal coherence destruction for any input beam. Hence the main aim of the present analysis is to optimise the transformation (1), (4) over possible spatial distributions of initial field $\mathcal{E}(\mathbf{r})$, what can be done via solving variational problem on minimum of double integral

$$\mu U^2 = 2 \int d^2 r_1 \int d^2 r_2 \, I(\mathbf{r}_1) I(\mathbf{r}_2) \frac{1 - \cos(\eta T [I(\mathbf{r}_1) - I(\mathbf{r}_2)])}{\eta^2 T^2 [I(\mathbf{r}_1) - I(\mathbf{r}_2)]^2} \tag{5}$$

under additional constrain of constant energy

$$\int d^2 r I(\mathbf{r}) = U, \tag{6}$$

where $I(\mathbf{r}) = |\mathcal{E}(\mathbf{r})|^2$ — input intensity profile.

So far the above two functionals do depend on incident intensity only, the task can be simplified by transition to integration over beam intensity with proper introduction of quasi-distribution function $P(I)$:

$$K(t_1,t_2) = \frac{1}{T} \int_0^{I_0} dI \, P(I) I \exp\{i\eta I (t_1 - t_2)\}, \qquad (0 \le t_1, t_2 \le T), \tag{3a}$$

$$\mu U^2 = 2 \int_0^{I_0} dI_1 \int_0^{I_0} dI_2 \, P(I_1) P(I_2) I_1 I_2 \frac{1 - \cos(\eta T [I_1 - I_2])}{\eta^2 T^2 (I_1 - I_2)^2}, \tag{5a}$$

$$\int_0^{I_0} dI \, P(I) \, I = U. \tag{6a}$$

Function $P(I)$ has a meaning of measure of contribution into these integrals due to field points of given intensity. In particular important case of axially symmetric and monotonous dependence $I(r)$ it is easy to see that $P(I) = 2\pi r(I) |\partial r / \partial I|$. Here additional condition of finite maximal intensity I_0 is implied. It is reasonable for any real field distribution (but it does not the case for speckle model).

At sufficiently high values of η one can do further simplification on the base of equality

$$(1 - \cos \eta x)/\eta^2 x^2 \approx \delta(x) \pi / \eta,$$

and then (5a) takes the form

$$\mu U^2 = \frac{2\pi}{\eta T} \int_0^{I_0} dI\, P^2(I)\, I^2. \qquad (5b)$$

Then it is readily seen that maximal coherence destruction is achieved when

$$P_{MAX}(I) = \frac{U}{I_0} \frac{1}{I},$$

what in coordinate representation takes the form of Gaussian beam

$$I_{MAX}(r) = I_0 \exp(-\pi r^2 I_0 / U), \qquad (7)$$

and appropriate overall degree of coherence is

$$\mu = \frac{2\pi}{\eta T I_0}. \qquad (8)$$

3 DISCUSSION

The derived profile of input beam has some unique features, that makes it especially attractive for nonlinear speckle-noise reduction. First, such fields are easy to generate, to control and to operate.

Second, in bulk a layer of nonlinear media[1] diffractional mixing diminish the resulting decoherence of a field. Gaussian beam has absolutely minimal diffractional divergence and consequently it allows to use thicker layers, increasing the efficiency of coherence transformation.

At last, it should be noted that according to paper[4] zones of identical intensity (for (7) these are concentric circles) belong to one mode or, in other words, produce coherent radiation. In order to generate output light with desired structure of spatial coherence function one just need to mix the field after nonlinear media on suitable stationary diffuser.

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4 REFERENCES

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